Comparison of the VTX detector response to testbeam data.

1 Introduction

This note is written as a response to the Annual Review of PHENIX VTX Project (June 2009) homework item.

> *Recommendation 2: Simulations to reproduce the Fermilab 120 GeV proton beam data should be carried out, including charge sharing. This should be done quickly within one month and summarized in a brief note. In particular, we would like to see the x and u strip hit distribution and noise data reproduced both with the simulation as it is currently, and with the simulations correctly tuned (if necessary) to adequately reproduce the test beam data. For completeness, a similar study should be done for the pixels.*

Original calibration of the stripixel detector response was carried out with 5-20 GeV pions, which, in principle, could differ in their ionization losses from 120 protons. Also, the review committee noted that X/U charge sharing width in the simulations appeared narrower than in the testbeam results. The present note addresses these issues.

2 Stripixel layers

Calibration of the stripixel detector response in simulation was done using 120 GeV single protons generated at $\phi = 0.15$ and $\theta = 0.0$. This corresponds to perpendicular incidence of protons on third layer of the VTX detector. Results from third layer only were used in this study.

Full GEANT simulation of 120 GeV protons going through the PHENIX experimental setup was done, and detector response was calculated. Detector response included charge sharing beteen adjacent stripixels, and X and U readuouts, and also noise.

ADC values in simulation were calculated as follows:

$$ADC = E_{GEANT} \cdot 0.28eV^{-1} \cdot ADCGAIN$$

where E_{GEANT} is ionization energy loss calculated by GEANT, $0.28eV^{-1}$ is inverse ionization potential for silicon (number of electron-hole pairs produced per 1 eV) and $ADCGAIN$ is the coefficient that has to be calibrated. This coefficienct is, essentialy, a channel width of the ADC converter.

ADC distribution for X and U readouts in simulation is shown in fig. 1 and fig. 2 by blue points, along with the Fermilab testbeam results shown as black histogram. As one can see, there is very good agreement between the two distributions, both in most probable energy deposit, and signal/noise ratio.

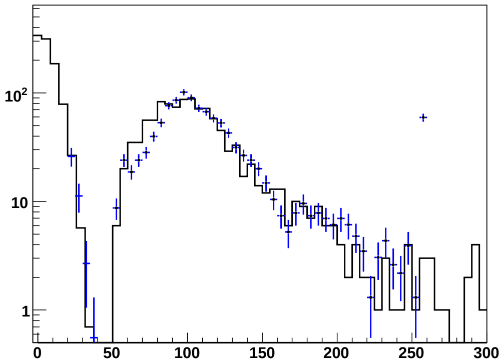


Figure 1: ADC distribution for X readout for testbeam (black histogram) and simulation (blue points). Note, that in simulation noise is cut off below ADC=20.

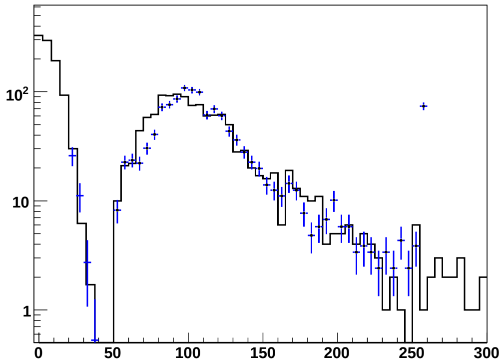


Figure 2: ADC distribution for U readout for testbeam (black histogram) and simulation (blue points). Note, that in simulation noise is cut off below ADC=20.

Charge sharing between X and U readouts in simulation is done by generating a Gaussian random number Q_{RND}, with mean value 0, and width σ, which was used to reproduce fluctuations in charge sharing between two readouts as follows: $Q_{RND} = (Q_X - Q_U)/(Q_X + Q_U)$. Here Q_X is charge in X readout, Q_U is charge in U readout, and $Q_X + Q_U$ is total deposited charge. After original calibration Gaussian width of the charge sharing in simulation σ was 0.10. After more detailed comparison with the test beam results we found that this was too small.

Charge sharing between X and U readouts after new calibration is shown in fig. 3 for simulation and test beam results. Gaussian fit to the test beam results gives $\sigma_{data} = 0.136 \pm 0.003$. Note, that this is smaller than what was reported during the review, because at that time wrong timing for plotting the data was used. Also note that fig. 3 was done for charge sharing Gaussian width $\sigma = 0.109$, while fit gives $\sigma_{data} = 0.136 \pm 0.003$. The difference with the fit result is due to additional widening after noise is added.

Charge sharing between adjacent stripixels is done proportional to the path length.

List of old and new detector response parameters in simulation is shown in table 1.

Table 1: Old and new detector response parameters for stripixel layers in simulation. Pixel layers parameters are unchanged.

	old	new
ADCGain	0.0038	0.0038
X/U charge sharing Gaussian width	0.100	0.109
Gaussian width of noise (ADC channels)	10	10
Noise cutoff (ADC channels)	21	21
Clustering threshold (ADC channels)	40	40

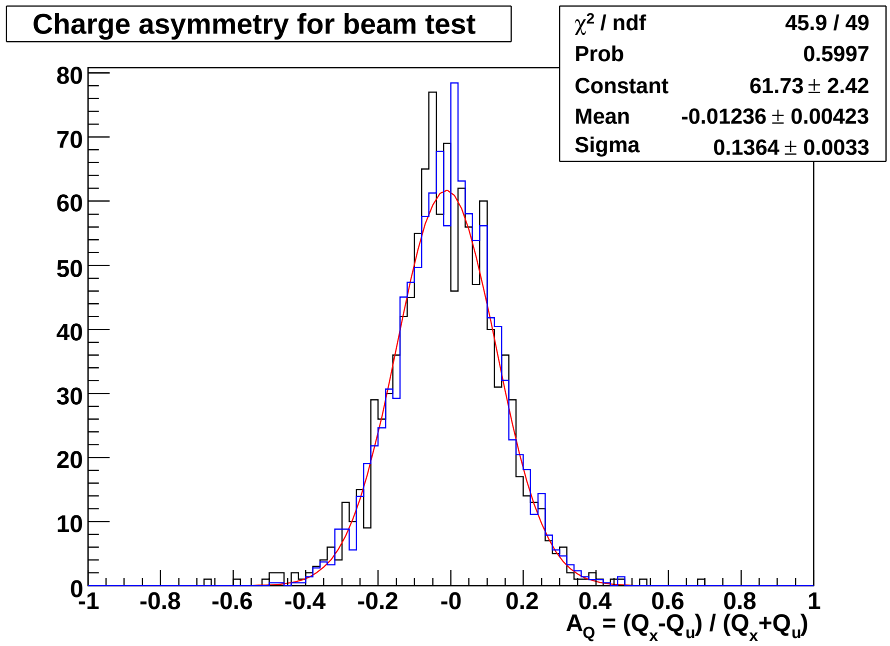


Figure 3: Charge sharing distribution for for test beam results (black) and simulation (blue). Red curve is the fit to the test beam results.

3 Comparison of 120 GeV protons with MIPs

The signal-to-noise ratio for one (X or U) stripixel readout is 10, as measured during beam test and reproduced in simulation for 120 GeV protons with perpendicular incidence on the detector. Note, that most probable (not mean) energy deposit is used in calculating this number.

However, since 120 GeV protons are not MIPs, the question is what signal-to-noise ratio we will have for minimum ionizing particles. This question was answered by doing a full simulation for single 3.4 GeV protons, which are minimum ionizing. The result of this study are shown in fig. 9. For comparison, fig. 10 shows similar ADC distribution for 120 GeV protons. From these plots it follows that the difference in most probable energy deposit for MIPs and 120 GeV protons is less than 5%.

Plots of mean dE/dx vs momentum in textbooks show a larger relativistic rise, by about 25% from MIP (3.4 GeV proton) to 120 GeV proton. We note that mean dE/dx and the most probable dE/dx value is different, and the relativistic rise effect is smaller in the most probable dE/dx. In addition, the value of mean dE/dx in textbooks is calculated for a thick material, and the relativistic rise in a very thin material is smaller. The difference between the MIP and FNAL test beam (120 GeV proton) is smaller since we use the most probable dE/dx and the silicon detector is very thin. Thus, FNAL test beam results demonstrated that the stripixel detector has S/B = (the most probable dE/dx)/(noise width) = 10 for one readout channel (X or U).

4 Pixel layers

The two inner VTX layers consist of pixels, which have one bit readout. As a result, making exactly the same study for pixel layers can not be done. However, some comparison of simulation to the data is possible.

Fig. 4 and fig. 5 show number of pixels per cluster for the test beam and simulation. Good agreement can be seen.

Fig. 6 and fig. 7 show residuals distribution in ϕ and Z directions for the test beam results. The residuals were calculated as a difference between hit position and a straight line track reconstructed from hits in three layers (see addendum A). Fit results are $6 \pm 2 \mu m$ for the ϕ direction, and $60 \pm 11 \mu m$ in Z direction. Intrinsic resolution calculated from these numbers (see addendum B) is $14 \pm 6 \mu m$ and $150 \pm 30 \mu m$ respectively, which is in good agreement with theoretically expected values.

Fig. 8 shows residuals distribution in ϕ and Z directions for the simulation of the FNAL test beam. Gaussian fit results in this case are $6 \pm 0.6 \mu m$ for the ϕ direction, and $50 \pm 4 \mu m$ in Z direction. Intrinsic resolution calculated from these numbers is $14 \pm 2 \mu m$ and $120 \pm 12 \mu m$ respectively. Both ϕ and Z results are in good agreement with the test beam results.

5 Conclusions

- VTX detector response was calibrated for two outer stripixel layers using 120 GeV simulated protons and compared to the results of a test beam measurements at Fermilab.

- Most probable energy deposit was already calibrated properly, because 5-20 GeV pions used for the original calibration had approximately the same most probable energy deposit as 120 GeV protons.

- Signal to noise ratio was already correct in the original calibration.

- Charge sharing parameter between X and U readouts had to be increased from 0.10 to 0.109 in order for the simulation to reproduce properly the test beam results.

- The difference in most probable energy deposit between 120 GeV protons and MIPs is 4.3%. Thus, the FNAL beam test results show that the S/B of the stripixel detector is 10 for one readout channel.

- For the pixel layers simulation properly reproduces number of pixels in a cluster and space resolution in both ϕ and Z directions.

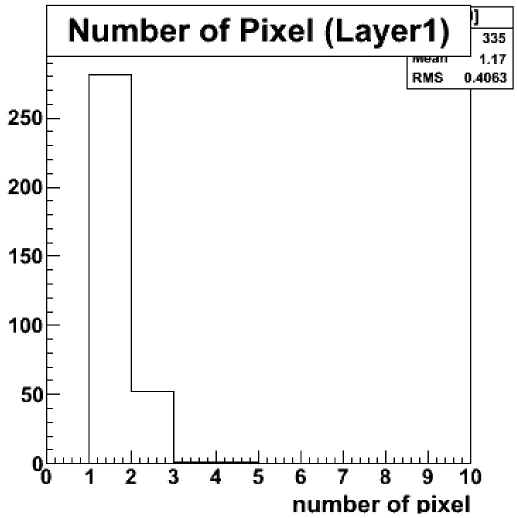


Figure 4: Number of pixels per cluster for test beam results (pixel layers).

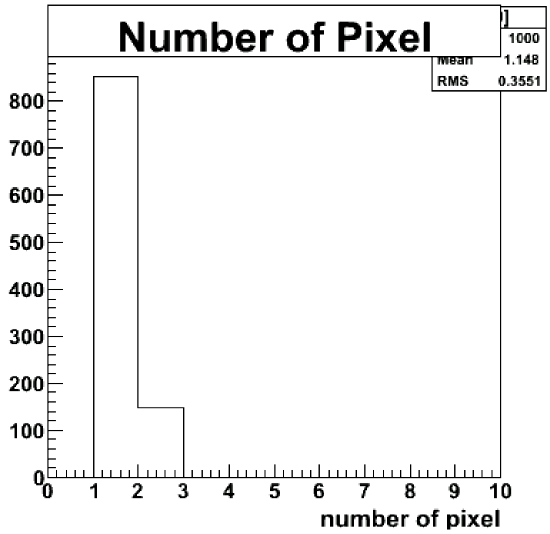


Figure 5: Number of pixels per cluster for the simulation (pixel layers).

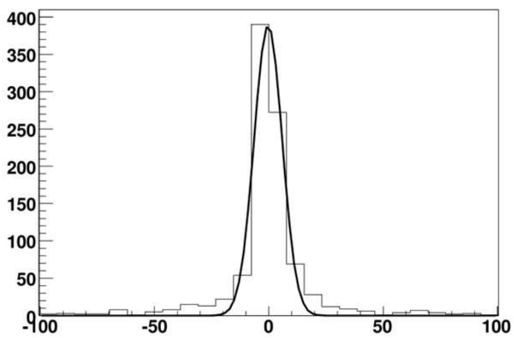


Figure 6: Reiduals in ϕ direction from test beam data in pixel layers. Horizontal axis is in μm.

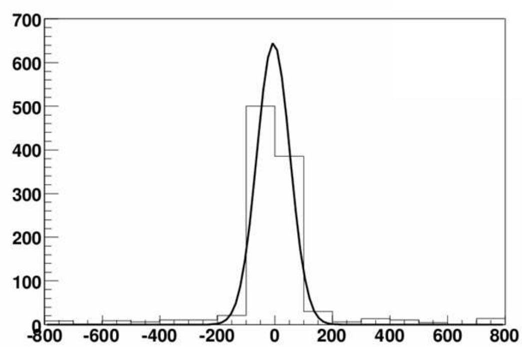


Figure 7: Residuals in Z direction from test beam data in pixel layers. Horizontal axis is in μm.

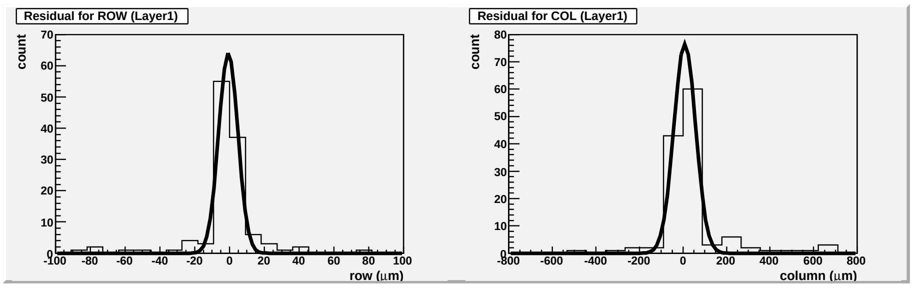


Figure 8: Residuals in ϕ (left) and Z (right) directions for pixel layers in simulation. Horizontal axis is in μm.

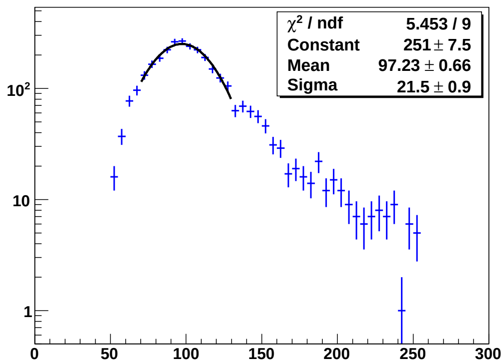


Figure 9: ADC distribution for 3.4 GeV protons (MIPs).

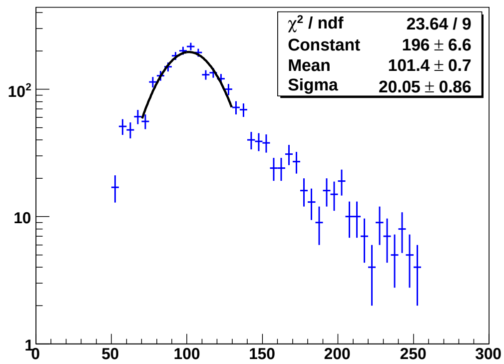
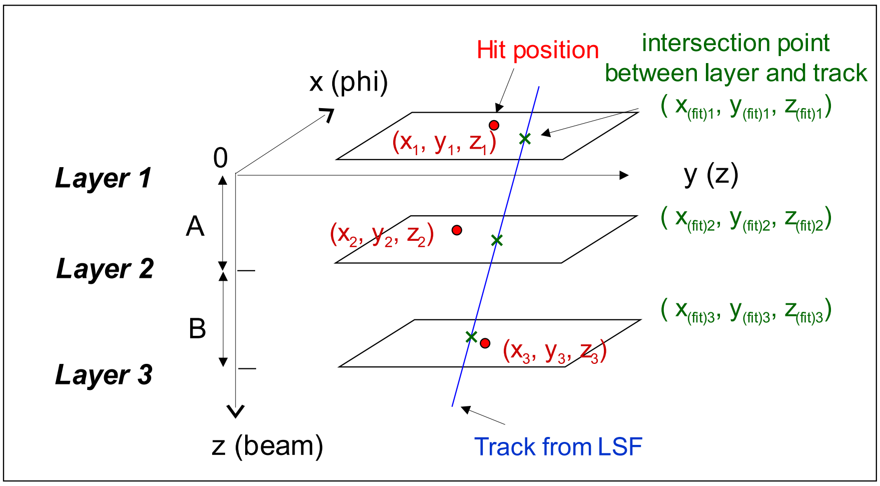


Figure 10: ADC distribution for 120 GeV protons.

Addendum A

Residual Calculation



For example, residual of x direction on Layer 1 is

$$res_1 = x_1 - x_{(fit)1} = \frac{B}{2(A^2 + B^2 + AB)}\left(Ax_1 - (A+B)x_2 + Bx_3\right)$$

Addendum B

Intrinsic Resolution Calculation

$$\begin{cases} \sigma^2_{res1} = \left(\dfrac{\partial res_1}{\partial x_1}\sigma_{x_1}\right)^2 + \left(\dfrac{\partial res_1}{\partial x_2}\sigma_{x_2}\right)^2 + \left(\dfrac{\partial res_1}{\partial x_3}\sigma_{x_3}\right)^2 \\ \sigma^2_{x_1} = \sigma^2_{\text{int}} \\ \sigma^2_{x_2} = \sigma^2_{\text{int}} + \sigma^2_{m_1} \\ \sigma^2_{x_3} = \sigma^2_{\text{int}} + \sigma^2_{m_2} \end{cases}$$

Multiple Scattering

Intrinsic Resolution

Multiple scattering

$$< \theta_0 >^2 = \frac{13.6MeV}{\beta p}\sqrt{\frac{x}{X_0}}\left[1 + 0.038\ln\left(\frac{x}{X_0}\right)\right] \Rightarrow \begin{array}{l} \sigma_{m_1} = 0.98\mu m \\ \sigma_{m_2} = 18.6\mu m \end{array}$$

Experimental Result
σ_{int}(phi) : 14±6mm
σ_{int}(z) : 150±30mm

Theoretical Value:
σ_{int}(phi) : 14.4mm = 50/sqrt(12)
σ_{int}(z) : 122.7mm = 425/sqrt(12)